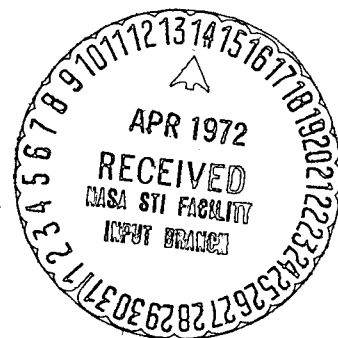


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DEVELOPMENT OF TECHNIQUES
AND ASSOCIATED INSTRUMENTATION
FOR HIGH TEMPERATURE
EMISSIVITY MEASUREMENTS

CONTRACT NAS 8-26304
CR-123547

SIXTH QUARTERLY PROGRESS REPORT
FOR THE PERIOD 29 DECEMBER 1971 TO 28 MARCH 1972

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA

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FOREWORD

This document was prepared by the Thermophysics Group of the Infrared Programs organization of the Engineering Sciences Directorate, Lockheed Palo Alto Research Laboratory, Lockheed Missiles & Space Company, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. This is the sixth quarterly report; it describes the technical activities carried out under Contract NAS 8-26304 during the period 29 December 1971 to 28 March 1972. The work was administered under the Technical direction of Mr. Roger Harwell, Materials Division, Astronautics Laboratory, Marshall Space Flight Center. Previous reports distributed under this contract include the following:

QPR #1, N-JF-70-1, 6/29/70 to 9/29/70
QPR #2, N-JF-71-1, 9/29/70 to 12/29/70
QPR #3, N-JF-71-2, 12/29/70 to 3/29/71
Interim, N-JF-71-3, 6/29/70 to 6/28/71
QPR #4, N-JF-71-4, 6/29/71 to 9/28/71
QPR #5, N-JF-72-1, 9/29/71 to 12/28/71

ABSTRACT

This report describes the progress during the sixth quarterly reporting period on construction and assembly of a test facility to determine the high temperature emittance properties of candidate thermal protection system materials for the space shuttle. This facility will provide simulation of such reentry environment parameters as temperature, pressure, and gas flow rate to permit studies of the effects of these parameters on the emittance stability of the materials. Also reported are the completed results for emittance tests on a set of eight Rene 41 samples and one anodized titanium alloy sample which were tested at temperatures up to 1600°F in vacuum. The data includes calorimetric determinations of total hemispherical emittance, radiometric determinations of total and spectral normal emittance, and pre-and post-test room temperature reflectance measurements.

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Section 1

INTRODUCTION

Design of a radiatively cooled thermal protection system for reusable entry vehicles is dependent upon accurate emittance values for the exterior surface coatings or materials under the conditions of the entry environment. To achieve the optimum in system design, the total hemispherical emittance must be high, at elevated temperatures, and this property should be stable during entry. To accomplish the multiple reuse goal, the emittance stability should be maintained for many entry exposures. Because the radiation properties of candidate surfaces may be dependent upon the elevated temperature exposure conditions, it is necessary to evaluate their emittance in an environment which simulates the entry conditions as nearly as is practical within funding and time limits. During the initial phase of this program, investigations were made into the potential of using existing facilities to perform emittance studies for this application. As none met the requirements for simulation together with adequate emittance measurement capability, a new facility was prepared. This apparatus provides a capability for total and spectral emittance measurements on metals and ceramic coatings to 3000°F at pressures of 10^{-6} to 760 torr in a static atmosphere or with a flow of air directed onto the test surface. The air flow velocity may be varied from subsonic to Mach 3, and provision is included for heating the air stream to 3500°F. The feasibility of using an rf plasma heater, which would minimize problems of specimen contamination, is being investigated.

After completion of apparatus checkout and calibration, emittance tests will be conducted on seven candidate materials to evaluate their radiative properties under predicted space shuttle orbiter entry conditions of temperature and pressure with supersonic flow. Additional testing will be done to assess the effects of flow velocity and air temperature on emittance for seven materials. The materials to be investigated are: 1, oxidized Rene 41; 2, oxidized HS-188;

3, oxidized TDNiCr; 4, Cb129 with VHL09 coating; 5, Cb752 with R512E coating; 6, Lockheed water-proof LI-1500 coating; 7, McDonnell-Douglas water-proof HCF coating.

The technical activities and accomplishments during the sixth quarterly reporting period for this contract are summarized in Section 2 of this report. Progress towards completion of the experimental test apparatus is reviewed in Section 3 and the status of the materials test specimen program is discussed in Section 4. Section 5 contains a summary of final results for emittance tests which were made on eight René samples and are anodized Ti-6Al-4V sample for which preliminary total emittance data were reported in the last Quarterly Progress Report. Activities planned for the next reporting period are described in Section 6.

Section 2

SUMMARY

Activity during the 3-month period covered by this report concentrated on completing the assembly and checkout of the experimental apparatus, preparing for the materials test program and completing the reduction of total and spectral emittance test data for nine MSFC-supplied specimens of Rene 41 and Anodized Ti-6Al-4V. Vacuum system checkout tests with the large (850 cfm) pump have been completed and associated vibration problems have been successfully eliminated. A 15 KVA power transformer has been installed to supply the high current electrical power for heating the sample test strips. Various other minor jobs including fabrication and installation of instrumentation feed-thrus for monitoring sample and chamber temperatures and pressures, coating of the interior chamber walls, water-line hookups and spectral transmission measurements for the KBr view-port windows, have also been completed.

Two cold flow nozzles designed to provide Mach 1 and Mach 3 flow rates have been fabricated and assembled with the nozzle holder and flow duct attachment which mounts to the test chamber wall and will direct the flow onto the front face of the sample. An instrumented test plate has been fabricated to calibrate the cold flow characteristics of these nozzles; however, calibration tests have been postponed while the chamber vibration problem was being eliminated. These tests are to be completed during the next monthly reporting period.

Proof tests to determine the suitability of a rf plasma torch unit for heating air required for the hot gas flow tests were made in January at the manufacturers plant. The tests showed that the proposed unit was not suitable for operation at the pressures and mass-flow rates required for this program. Alternate methods for satisfying the hot air requirement have been considered and will be proposed for MSFC approval.

Total and spectral response characteristics for the Barnes radiometer have been calibrated for blackbody source temperatures between 200°F and 1850°F. A high temperature blackbody source operated by the Measurements Standards Laboratory of IMSC will be utilized to extend the calibration curves to 2500°F.

All of the sample alloy materials to be tested in this program have been received except for the Cb 129Y alloy, which is expected within the next two weeks. Arrangements for the heat-treatments and/or coatings for the sample strips are presently being completed.

Final analyses of the total and spectral emittance data for eight Rene 41 samples and one anodized Ti alloy sample tests for MSFC at the end of last year have been completed. Preliminary results were reported in the last quarterly report (N-JF-72-1) and the final results, which are revised to account for slightly higher sample temperatures at 1600°F, are summarized in Section 5.

Section 3

EXPERIMENTAL APPARATUS

Progress towards completion and checkout of the experimental test apparatus during the past three months is summarized in the following subsections. Several problems have been encountered which have required additional attention and effort to overcome and which therefore have created some slippage from the planned completion schedule; however, with the exception of the rf plasma air-heating system, the assembly of the test apparatus is now essentially complete.

3.1 Test Chamber and Vacuum System

Installation of electrical services for the 850 cfm vacuum pump was completed in January and checkout tests of the pump operation have been completed. During the initial checkout test, excessive contraction of the 8-inch diameter bellows located between the pump and the foreline trap was noted. As a result, large strains and vibrations occurred in the vacuum line pipes and the test chamber. Most of this problem was successfully eliminated by installing an additional fixed support for the trap which maintained the bellows at its proper operational extension; however, an additional bellows between the test chamber and the 8-inch vacuum valve was deemed necessary in order to completely eliminate vibrations from the pump to the test chamber. This bellows has just been received and installed and a final vacuum-system checkout test is underway.

A 15 KVA, 220-volt power transformer has been obtained and connected to the upper and lower sample electrodes of the test chamber. This unit will supply the high current, (up to 750 amps at 20 volts), electrical power for heating the test specimens. Connections between the secondary output busses and the test chamber electrodes are water-cooled copper tubes. Control to the primary side of the transformer will be through a Research Incorp. variable voltage supply which can be controlled either manually or by a Data-Trak Programmer unit in conjunction with a Therman Controller Unit.

Instrumentation feed-thrus for the read out of sample and test chamber temperatures (thermocouples) and chamber pressures, (ion gauge, vacuum thermocouple, and an electronic manometer), have been installed. The thermocouple feed-thru contains extension leads for six Pt 6% Rh/Pt 30% Rh thermocouples, (for sample temperature instrumentation); two Pt/Pt 13% Rh thermocouples; and four Chromel/Alumel thermocouples, (for chamber wall temperature monitors).

Additionally, the spectral transmittance of the 85 mm diameter by 13-mm thick KBr windows for the sample view-ports have been checked and found to agree with the literature values to within $\pm 0.5\%$. The normal transmittance curve is essentially flat at $91 \pm 0.5\%$ for the wavelength region between 0.5 and 20 microns, then drops off to 20% at $\lambda = 30\mu$. To minimize the possibility of radiant energy reflection problems within the test chamber, the interior walls have been coated with a black-matte-finish, epoxy-base paint (Cat-a-lac Black).

For the supersonic flow tests, two cold flow nozzles have been fabricated and assembled with the nozzle holder and gas duct assembly which mounts to the test chamber wall. An instrumented test plate with the same dimensions as for the emittance-test strips has also been prepared for determining the cold-flow characteristics of the air streams from these nozzles.

3.2 Plasma Gas Heating System

Proof tests to determine the feasibility of utilizing a TAFA Model 56 Induction Torch as a high purity air heater for the emittance-test apparatus were conducted at the TAFA facilities in Concord, N.H. in January. Specifications for the tests were written as follows: "The operation of a standard Model 56 torch with a 15 KW rf power supply at pressures from 10 to 100 torr and at mass flow rates from 100 SCFM (2.23×10^{-3} lbm/sec) of air up to as near 250 SCFM as is obtainable with the vacuum pumping system." These conditions were selected as representative of the cyclic hot gas flow test parameters required for this program.

The test equipment consisted of a 300 cfm vacuum pump coupled to a cylindrical, cross-shaped, water cooled vacuum chamber of 1-ft. diameter and 2-ft. length with a heat exchanger between the pump and the vacuum chamber. The Model 56 torch unit was mounted on the end of one arm of the chamber.

To meet the mass flow rate/pressure requirements for these tests, it was necessary to vary the torch power from very low values up to about 750 BTU/lbm. in order to obtain the desired stagnation temperature cycle. The proof tests showed that this torch unit, which was designed for operation at atmospheric pressures and higher mass flows and power levels, was not able to operate in the proposed manner. The principal difficulties encountered were high-voltage arcing and an unstable gas discharge which was attributed to poor power coupling to the gas. To improve the power coupling it was felt that considerable theoretical work was needed before a suitable low-pressure unit could be designed.

Following these tests, alternate methods for obtaining the high enthalpy air for the hot gas flow tests were considered and it was concluded that the induction torch method was the only one capable of providing the high purity, (uncontaminated), air stream necessary for these tests. Consequently, a new scheme for utilizing the unit was devised. The torch will be operated at nearly atmospheric pressure, at a high mass flow rate, and at a high power level. These parameters will be adjusted for optimum torch performance. The effluent from the torch will be directed into a heat exchanger in which the enthalpy of the air will be lowered to the desired value for the experiment. A fraction of the effluent will be pumped off to allow adjustment of the mass flow for the experiment. The remaining high enthalpy air will be supplied to the supersonic nozzle in the experiment at conditions suitable for the cycle plan. In this manner the torch can be operated separately from the experiment, and adjustments of the torch parameters that may be necessary to insure stable operation need not disturb the planned values of experimental parameters.

With the cooperation of TAFE, work is presently underway to specify the equipment needed and to plan a further set of proof tests to check the new scheme in operation. The equipment suggested by TAFE consists of their Model 56 Torch and associated feed lines. A calorimeter will be provided for use as a heat exchanger. The power supply quoted is a 25 kW r.f. output model for this application because this is the minimum power level at which TAFE has had success in sustaining an air plasma and still retaining a range of operating points. Upon completion of these plans, the equipment and cost requirements will be forwarded to MSFC for approval to proceed with the proof-testing of this scheme.

3.3 Radiometer

Preliminary calibration data for the Barnes radiometer has been obtained for the unfiltered (total) operating mode and for the nine filtered (spectral) operating modes. A description of the filters was given in the last Quarterly Progress Report. The data consists of radiometer signal outputs for each operating mode (filter wheel position) vs. blackbody target temperature. The data was obtained at temperatures between 375°K and 1280°K (200°F to 1850°F) using an Infrared Industries Inc. Model 404 Blackbody with a 0.4-in. diameter aperture. The target distance, (blackbody-to-radiometer distance), was 30 inches.

An indication of the response range of the radiometer for each operating mode is given in Table 1. The total response range for the radiometer is from 0 to 9400 output units, i.e. radiometer detector output times amplifier attenuation units. A response of zero corresponds to the irradiance level obtained from a 331°K blackbody target. This is the operating temperature of the radiometer's reference cavity against which all incoming radiation levels are referenced. By extrapolation of the total radiation response data shown in Table 1, (for Filter Wheel Position 1-1), it is estimated that the maximum response capability of the radiometer (9400) will correspond to the total irradiance obtained from a 1600°K (2450°F) blackbody target. It is anticipated that this measuring capability will be adequate for the sample emittance

test program to be performed for this contract. If necessary, the maximum measuring capability should be easily extendable to higher target temperatures with the use of a neutral density filter.

In order to complete the radiometer calibration to 2500°F, a high temperature blackbody maintained and operated by the Measurement Standards Laboratory at IMSC will be used. This work is scheduled for completion within the next monthly reporting period.

TABLE 1

TOTAL AND SPECTRAL CALIBRATION DATA FOR THE BARNES
MODEL 12-511A RADIOMETER FOR BLACKBODY SOURCE TEM-
PERATURES BETWEEN 400 AND 1200°K

Black- Body Temp. (°K)	Response at the following Filter-Wheel Positions									
	1-1 (Total)	1-2 (1.42 μ)	1-3 (2.17 μ)	1-4 (2.70 μ)	1-5 (3.39 μ)	1-6 (4.26 μ)	1-7 (4.85 μ)	1-8 (5.46 μ)	2-1 (7.96 μ)	3-1 (7.8 μ -16.6 μ)
400	18.0	0	0	0	0	0.17	0.22	0.19	0.78	7.65
500	68.0	0	0	0.23	0.42	1.00	1.87	1.04	2.50	25.0
600	160	0.10	0.56	1.65	2.25	3.20	5.10	2.53	4.65	46.5
700	320	0.67	2.76	5.50	6.00	7.00	10.5	4.45	7.00	70.0
800	555	3.75	8.50	14.0	12.5	13.0	17.8	6.90	9.40	97.0
900	900	12.6	21.3	29.8	23.0	20.8	27.5	10.0	12.1	124.0
1000	1380	36.0	46.8	53.5	38.0	30.2	39.0	13.4	15.0	154.0
1100	2000	93.0	88.0	86.5	56.0	43.0	53.0	17.3	18.0	183.0
1200	2870	170	141.	131.	78.0	57.5	68.0	21.3	21.6	220.0

Section 4
MATERIALS TEST SAMPLES

All of the metal specimen materials to be tested in this program are presently on hand with the exception of the Cb-129Y alloy which is due within the next two weeks. In accordance with instructions received from MSFC, the following heat-treatments and/or coating procedures are planned for these samples:

- o René 41: a) Resolution heat treat at 2050°F for 1/2-hr. in vacuum or argon atmosphere, (with rapid cool down)
b) Age for 2-hrs at 1650°F in vacuum or argon
c) Oxidize for 2 hrs at 1650°F in air
- o HS-188: Oxidize for 10-mins. at 1900°F in dry air, then air cool.
- o TD NiCr: Oxidize for 30 to 60 mins. in air.
- o Cb 752: Coat with Vac-Hyd VH109 (No thermal treatment after coating is fired.)
- o Cb 129Y: Coat with Sylcor R512E. (No thermal treatment after coating is fired.)

In addition to the 1 x 12 x 0.040 inch emittance test strips, 1-in. diameter disks of each material will also be treated concurrently to provide samples suitable for determinations of the pre-test, room temperature emittance characteristics of the samples.

Section 5

EMITTANCE TEST RESULTS

Total hemispherical and total normal emittance test results for eight coated or oxidized René 41 samples and one anodized Ti-6Al-4V sample at temperatures up to 1600°F were reported in the last Quarterly Progress Report (N-JF-72-1). Since then, reduction of the spectral emittance data for these samples has been completed, and additional corrections to the thermocouple-indicated sample temperatures at 1600°F have been made, based on the results obtained from optical pyrometer temperature measurements of the samples at that temperature.

Comparisons of the absolute sample temperatures indicated by optical pyrometer readings at 1600°F, using ϵ_λ values at $\lambda = 0.65\mu$ indicated by the room-temperature reflectance measurements for each sample, with the temperatures indicated by the sample thermocouples showed the following:

- 1) Initial 1600°F test temperatures indicated by the sample thermocouples were low by about 0.5%, (5°K), relative to the optical pyrometer temperature indications. This difference is in addition to the edge-to-center temperature gradients which were observed with the optical pyrometer and which were corrected for in the original emittance computations.
- 2) After the 1600°F emittance-stability test periods for each sample, thermocouple-indicated temperatures were from 10 to 15°K lower than the optical pyrometer temperature indications.

These differences are attributed initially to thermal conduction loss effects through the 3-mil diameter thermocouple leads which were spot welded to the edges of each sample. The subsequent increase in the differences is attributed to a degradation of the thermal emf-vs-temperature calibration for the

thermocouples after exposure periods of 20 to 71 hours at 1600°F in vacuum.

The effect of these additional temperature corrections on the total emittance values reported in the last quarterly report, (N-JF-72-1, Table 3) is to lower the initial 1600°F test values by 0 to 2 percent and the final 1600°F test values by 1 to 4 percent. These changes are incorporated in the revised summary of test results shown in Table 2. It should be noted that optical pyrometer readings were not possible at the 800°F and 1200°F test temperatures, consequently no basis for correcting the thermocouple readings at these temperatures was obtained. If the changes in thermocouple calibration which were apparent after the 1600°F exposure periods were also present at the lower test temperatures, then the emittance values shown in Table 2 for the cooling portion of the test cycle are also probably high by between 1 and 4 percent.

Results of the spectral emittance determinations for each sample are shown in Figure 1 through 9. These determinations were made during the initial heating portion of the test cycle for each sample at 800°F, 1200°F and 1600°F, and again at 1600°F following the emittance-stability test exposures at that temperature. Exceptions are Sample E1 which was tested to 800°F only, and Sample A2 which failed as it was being heated from 1200°F to 1500°F.

Figure 1 shows the spectral emittance characteristics of the anodized Ti-6Al-4V sample (No. E1) at 800°F and at wavelengths from 1.5 μ to 15 μ . Short wavelength emittance characteristics inferred from room-temperature reflectance measurements of the center test-section area of the sample before and after the high-temperature emittance test are also shown. The infrared emittance values are in good agreement with the independently-measured total normal emittance values obtained for this sample at 400°F and 800°F, and show that the reason for the observed drop in ϵ_{TN} with increasing temperature is due to lower values for ϵ_{λ} in the region from 1.5 to 8 μ relative to the higher ϵ_{λ} values at $\lambda > 8\mu$. The pre-and post-test reflectance data indicate a slight increase (about 1%) in emittance (or absorptance) in the $0.6\mu \leq \lambda \leq 1.8\mu$.

Table 2

REVISED SUMMARY OF TEST RESULTS FOR NINE MSFC EMITTANCE TEST SAMPLES

Sample	Test Cycle	α_s	$\epsilon_T(75^\circ\text{F})$	$\epsilon_{TH}/\epsilon_{TN}$ at 800°F	$\epsilon_{TH}/\epsilon_{TN}$ at 1200°F	$\epsilon_{TH}/\epsilon_{TN}$ at 1600°F	Hours at T(max)
René I	Heating	0.95	0.88 →	0.87/0.94 →	0.87/0.93 →	0.87/0.92 →	69
	Cooling	0.94	0.86 ←	0.89/0.94 ←	0.90/0.93 ←	0.87/0.92 ←	
René II	Heating	0.92	0.86 →	0.82/0.87 →	0.83/0.88 →	0.85/0.89 →	20
	Cooling	0.95	0.86 ←	0.87/0.94 ←	0.87/0.92 ←	0.86/0.89 ←	
René 1	Heating	0.91	0.74 →	0.80/0.85 →	0.81/0.83 →	0.83/0.85 →	71
	Cooling	0.83	0.77 ←	—	—	0.84/0.86	
René 2	Heating	0.90	0.53 →	0.64/0.67 →	0.69/0.72 →	0.74/0.77 →	28
	Cooling	0.91	0.73 ←	0.78/0.85 ←	0.80/0.87 ←	0.79/0.85 ←	
René 3	Heating	0.90	0.60 →	0.71/0.78 →	0.76/0.82 →	0.80/0.84 →	70
	Cooling	$\left\{ \begin{array}{l} 0.90 \\ 0.94 \end{array} \right.$	0.73 ←	0.79/0.85 ←	0.80/0.86 ←	0.80/0.85 ←	
René C2	Heating	0.88	0.74 →	0.78/0.84 →	0.79/0.86 →	0.79/0.85 →	48
	Cooling	0.86	0.80 ←	0.83/0.89 ←	0.83/0.90 ←	0.82/0.89 ←	
René D2	Heating	0.88	0.73 →	0.78/0.83 →	0.78/0.84 →	0.78/0.84 →	22
	Cooling	0.90	0.77 ←	0.81/0.89 ←	0.83/0.91 ←	0.82/0.88 ←	
René A2	Heating	0.92	0.67 →	0.70/0.79 →	0.76/0.83	=	—
	Cooling	—	—	—	—	—	
<div><div>$\epsilon_{TH}/\epsilon_{TN}$ at 400°F</div><div>$\epsilon_{TH}/\epsilon_{TN}$ at 800°F</div></div>							
Ti-6Al-4V E1	Heating	0.88	0.80 →		0.75/0.79 →	0.72/0.78 →	69
	Cooling	0.90	0.80 ←		— ←	0.74/0.82 ←	

Note: $\epsilon_{TH}/\epsilon_{TN}$ values obtained at 1200°F and 800°F after the 1600°F test exposures are believed to be 1 to 3 percent too high due to thermocouple calibration changes.
See Discussion.

spectral region as a result of the emittance-stability-test exposure of 69 hours at 800°F in vacuum (10^{-5} Torr).

Figures 2 and 3 show spectral emittance data for the two Solar SP-43A-I coated René samples (No. 1 and No. II) at test temperatures of 800°F, 1200°F and 1600°F. The curves indicate that significant changes in ϵ_λ occurred for both of these samples; however, the net effect of the changes on the total emittance properties of the samples is small, and the data is in good agreement with the independently-measured ϵ_{TN} values at each temperature.

It should be noted that several of the ϵ_λ determinations for these two samples resulted in values greater than 1, which of course are not possible. The error in these determinations could be due to one or a combination of measurement errors in the following parameters: 1) sample temperature determination, 2) KBr window transmittance, 3) reference blackbody temperature, 4) blackbody mirror reflectance, or 5) blackbody and/or sample signal measurement errors. Errors in the window transmittance and mirror reflectance values used for these tests would be systematic for all the sample emittance determinations made in this study and are believed to not exceed ± 1 percent. Similarly, blackbody temperature indication errors would also be systematic for all the tests and are believed to not exceed $\pm 3^\circ\text{K}$, ($\pm 0.3\%$ at 1600°F). Signal measurements are believed accurate to $\pm 1\%$, (excluding operator reading errors), consequently errors in the signal ratios should not exceed $\pm 2\%$. The most likely source of error is in the sample temperature determinations; however, thermocouple and optical pyrometer readings have been carefully analyzed for each sample in order to minimize these errors and they are believed to not exceed $\pm 1\%$ at each test temperature. If the high ϵ_λ values for these two samples are indeed due to low T_s determinations, the "corrected" ϵ_λ values in the 1 to 5μ region will be significantly lower than are shown in Figures 2 and 3.

Pre-and post-test reflectance data for Sample No. I indicates that the room-temperature emittance of this sample in the $0.3\mu \leq \lambda \leq 1.8\mu$ region was essentially flat at 0.95 and did not change more than $\pm 2\%$ after 69 hours at

1600°F in vacuum. The initial room-temperature emittance curve for Sample No. II dropped-off considerably at $\lambda > 1.0\mu$ to a low of 0.83 at $\lambda = 1.84$. After a 20 hr. exposure at 1600°F in vacuum, however, the room-temperature emittance curve was similar to that for Sample #I. This change correlates with the initially lower total emittance values obtained for this sample, and the subsequent increase in total emittance after the 20-hr. stability test exposure.

Spectral emittance characteristics for the various oxidized René 41 test samples are shown in Figures 4 through 9. The data for Sample No. 1 (Fig. 4) indicates that at wavelengths greater than 2μ , ϵ_λ for this oxide coating was not highly temperature dependent and did not change significantly after 70 hours at 1600°F in vacuum. A large change in the room-temperature ϵ_λ values between 0.3μ and 1.8μ was indicated, however by the post-test reflectance measurements. This change correlates with the significant color change that was observed for this oxide coating at the conclusion of the high-temperature emittance test.

The initial ϵ_λ characteristics for Sample No. 2, (Figure 5), differed considerably from those for Sample No. 1 at 800°F and 1200°F and featured a broad-low-emittance band in the region from 7 to 15μ . At 1600°F, however, ϵ_λ was observed to increase dramatically at wavelengths longer than 5μ , and after 27 hrs. at 1600°F, ϵ_λ in the $2\mu < \lambda < 5\mu$ region also increased. These changes correlate well with the independently-measured total emittance values for this sample.

The initial ϵ_λ characteristics for Sample No. 3 (Figure 6) were similar to those for Sample No. 2, with the exception that the large increase in ϵ_λ at wavelengths longer than 7μ was not observed until after the 69-hr. stability-test period for this sample at 1600°F. After this exposure, both the spectral and the total emittance properties of these two samples were observed to be closely alike. Unusual color-change patterns were observed for the oxide

coating on Sample No. 3 after the high-temperature emittance tests. Post-test reflectance data for the lighter, yellow-green areas and the darker gray areas which developed on the front (viewed) face of the sample strip are shown by curves 6a and 6b on Figure 6.

The initial and final ϵ_λ characteristics for Samples No. C2 and D2 (Figures 7 and 8) were observed to be almost identical to one another and to those described earlier for Sample No. 1. Changes in the appearance of these samples after their high-temperature emittance tests was from an initial slate-gray color to a mottled yellow-green/gray color. These changes correlate with the differences indicated by the pre-and post-test reflectance data for these samples.

The initial ϵ_λ characteristics for the oxide coating on Sample No. A2 are shown in Figure 9 and are seen to be similar to those for Samples 2 and 3 at 800°F and 1200°F. No additional emittance data was obtained for this sample because of a sample-failure as it was being heated to 1500°F.

Fig. 1. Spectral Emittance of MSFC Anodized Ti-6Al-4V
Sample No. E1

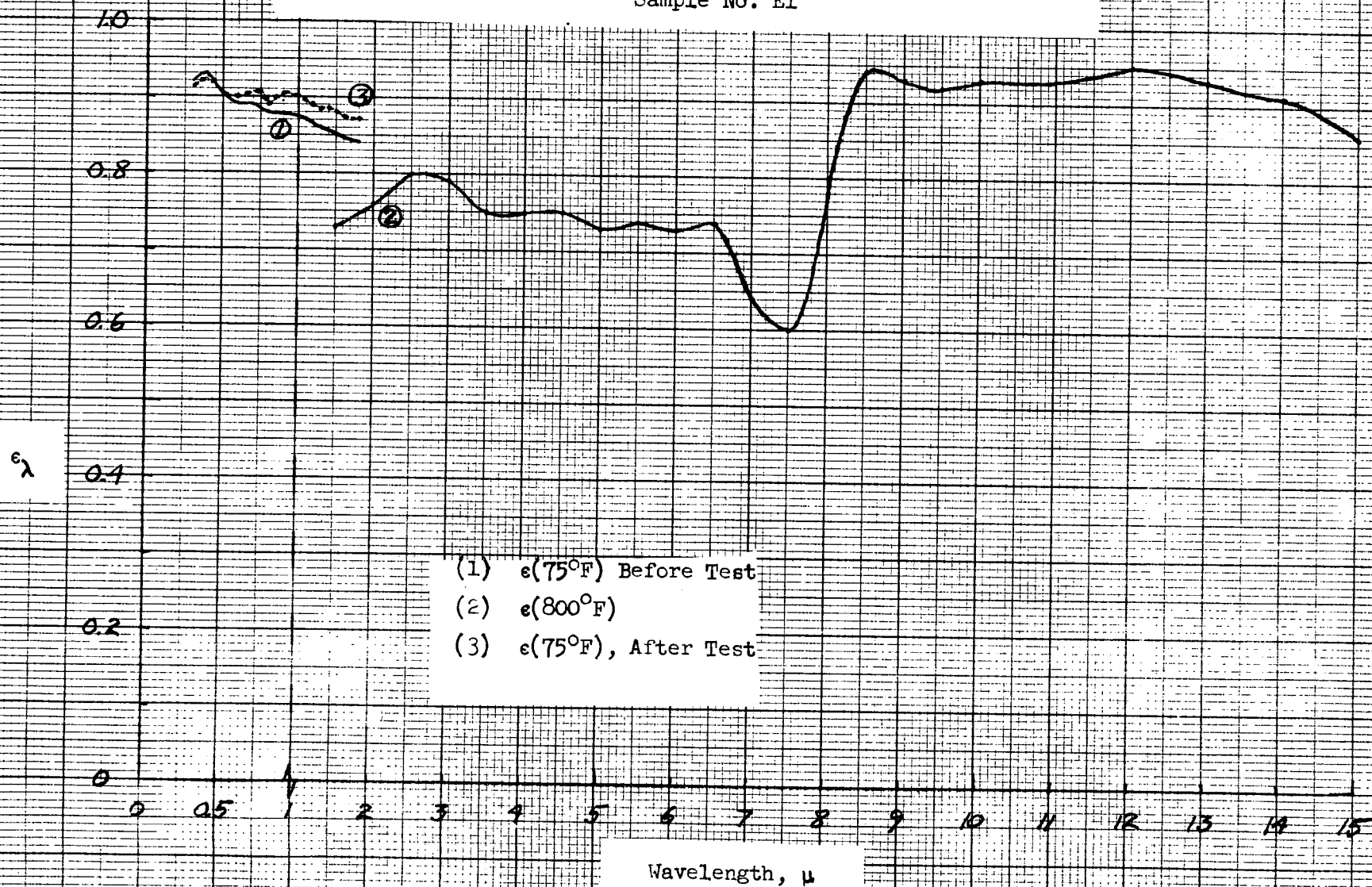


Figure 2. Spectral Emittance of MSFC René 41 Sample No. I with Single Coat of Solar SP-43A-I.

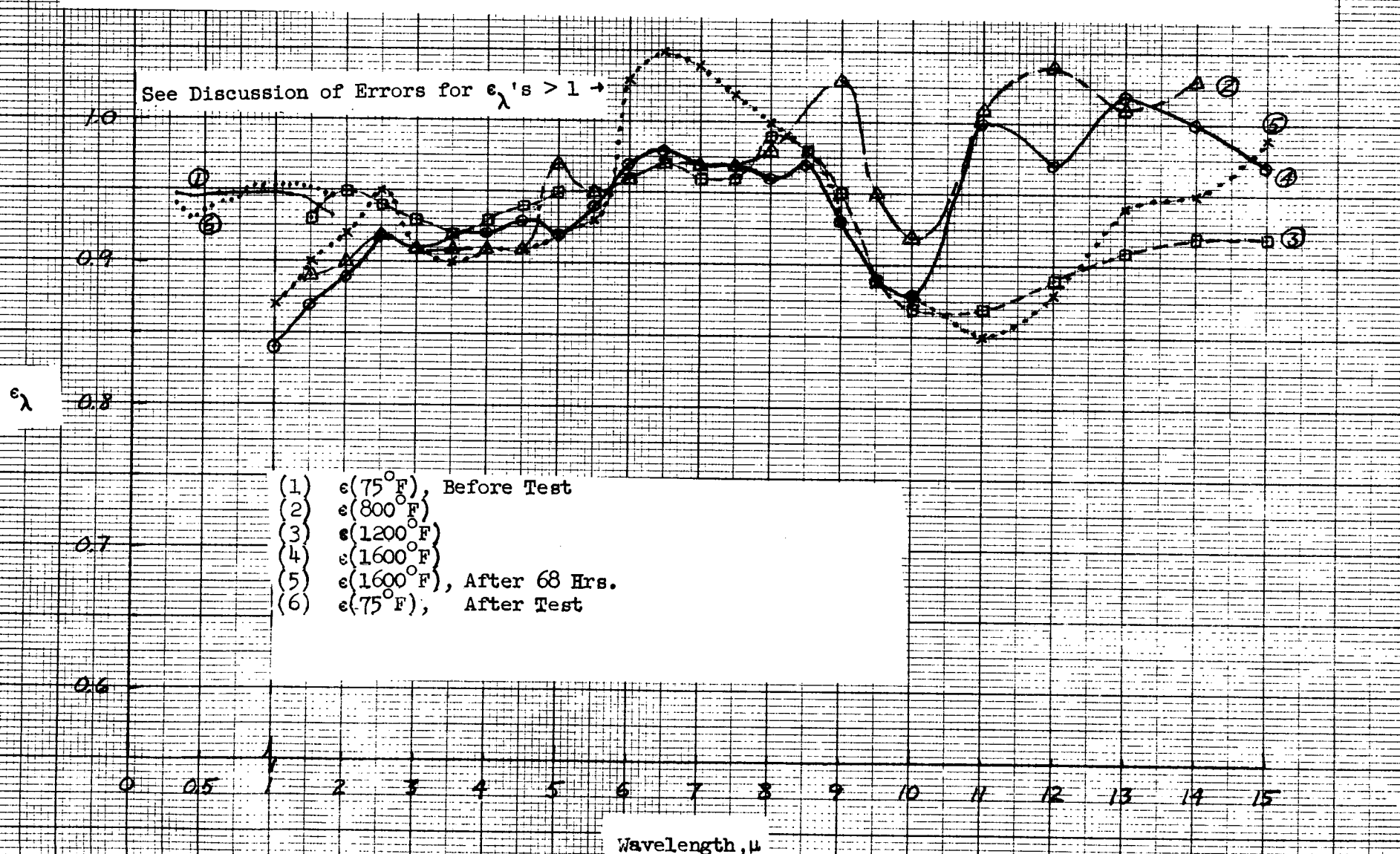


Figure 3. Spectral Emittance of MSFC René 41 Sample No. II with Single Coat (Dipped) of Solar SP-43A-I.

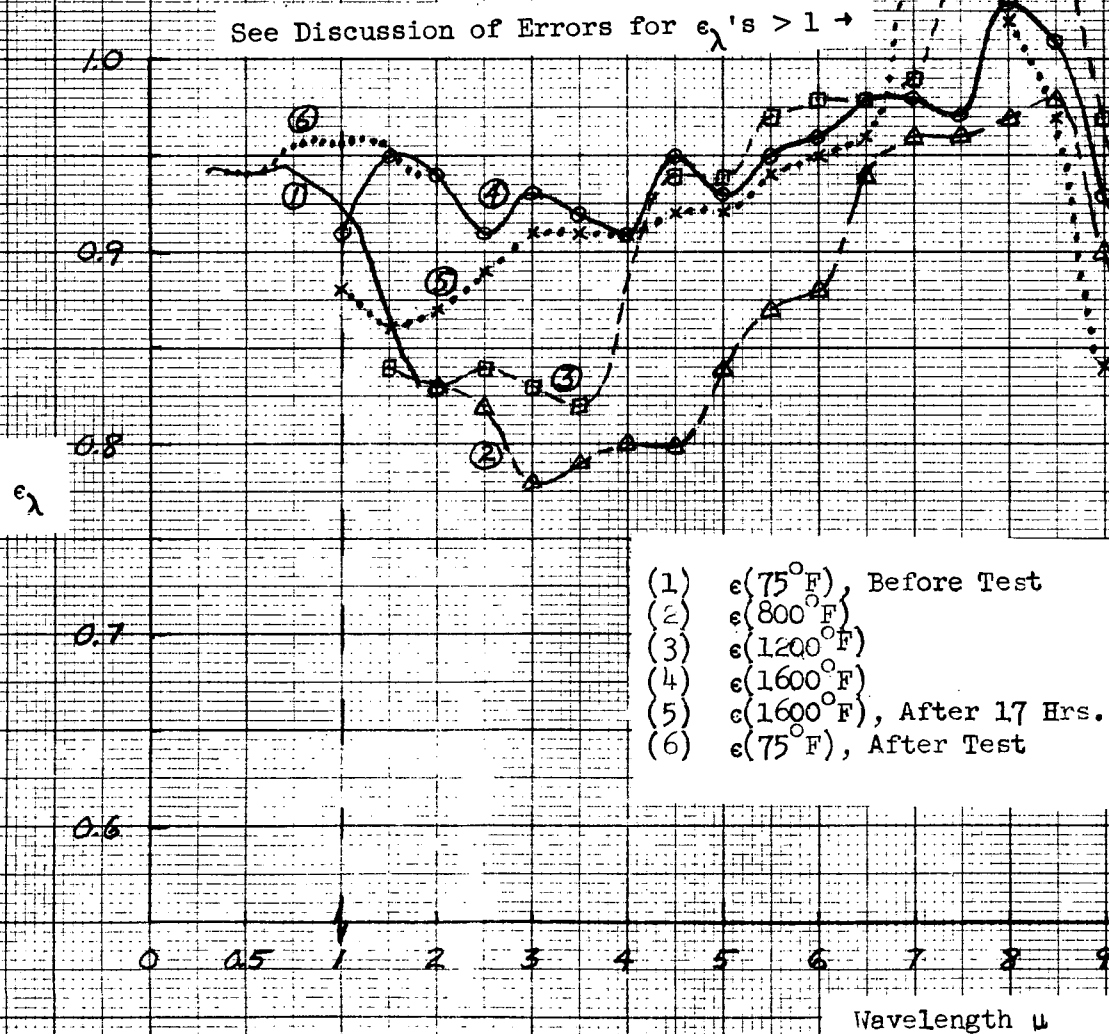


Figure 4. Spectral Emittance of MSFC Oxidized Rene 41 Sample No. 1.

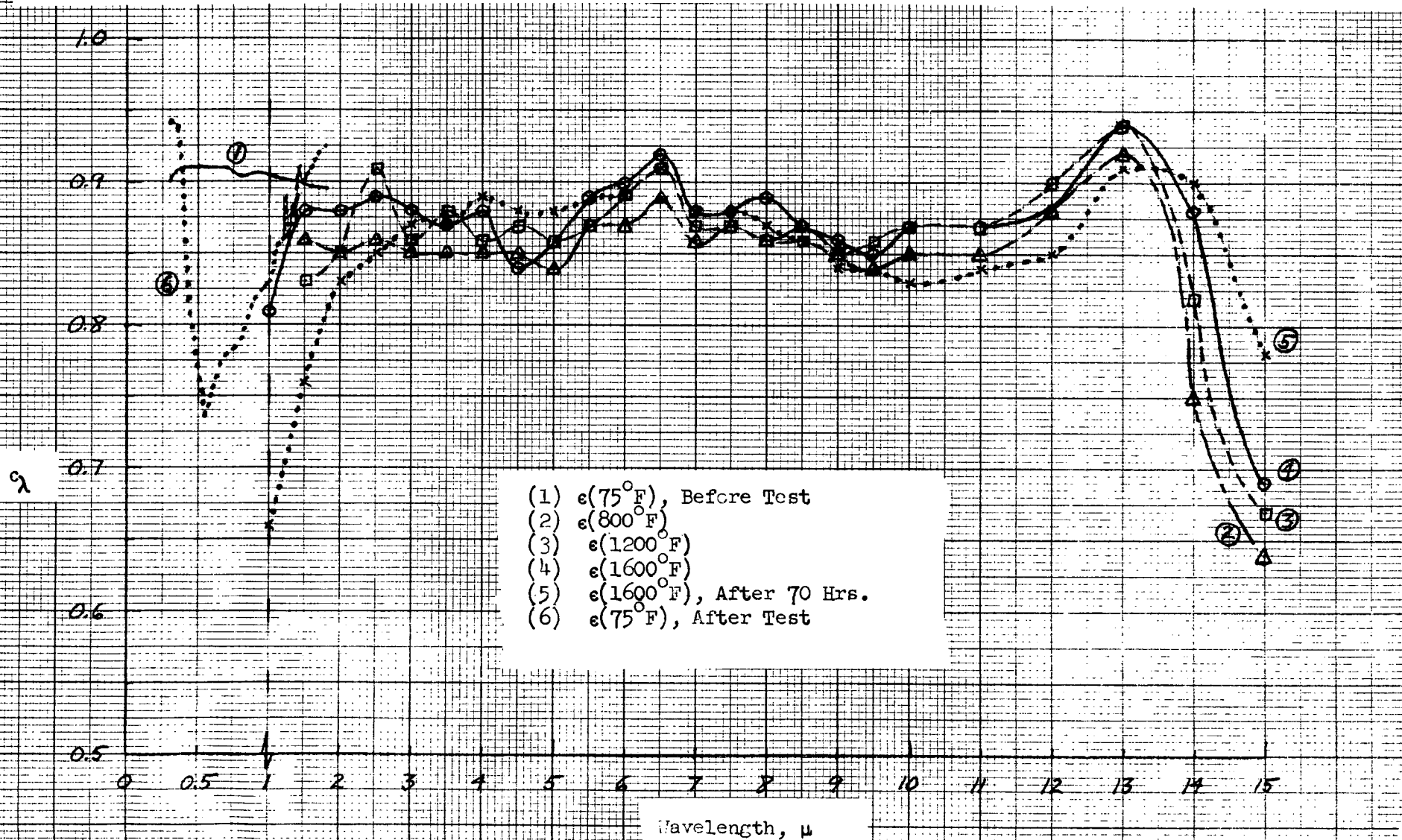


Figure 5. Spectral Emittance of MSFC Oxidized Rene 41 Sample No. 2

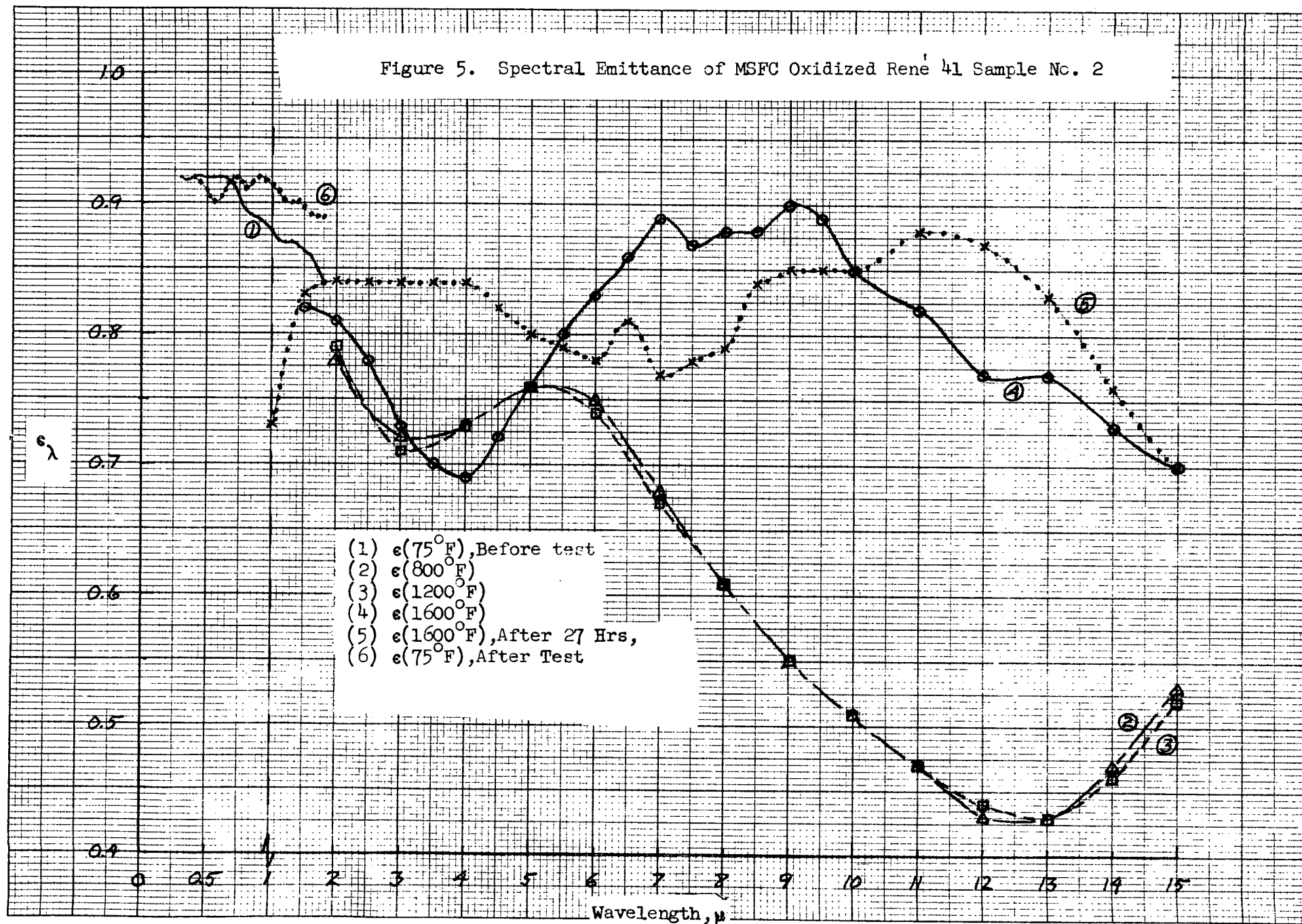


Figure 6. Spectral Emittance of MSFC Oxidized Rone 41 Sample No. 3

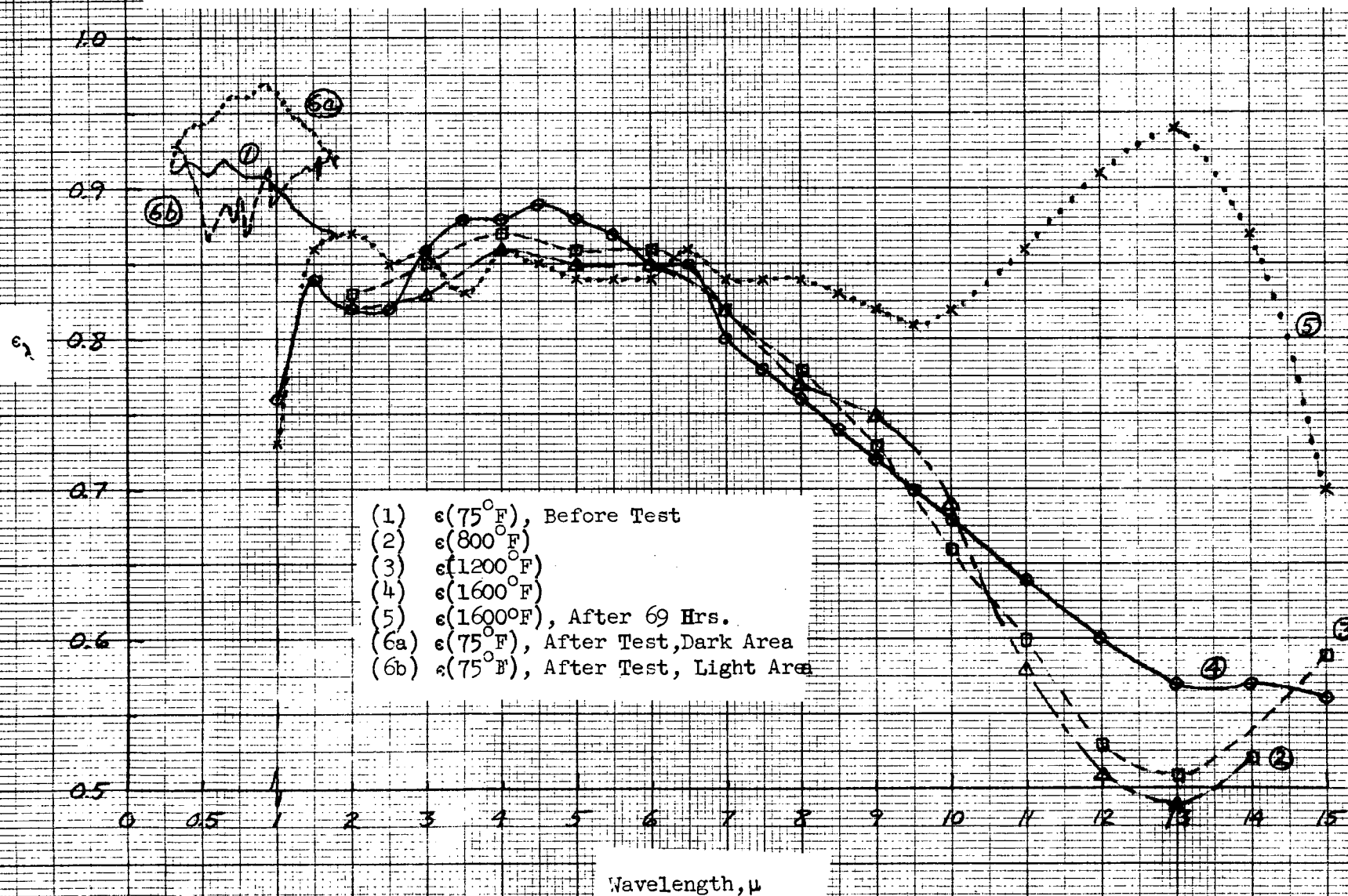


Figure 7. Spectral Emittance of MSFC Oxidized Rene 41 Sample No. C2.

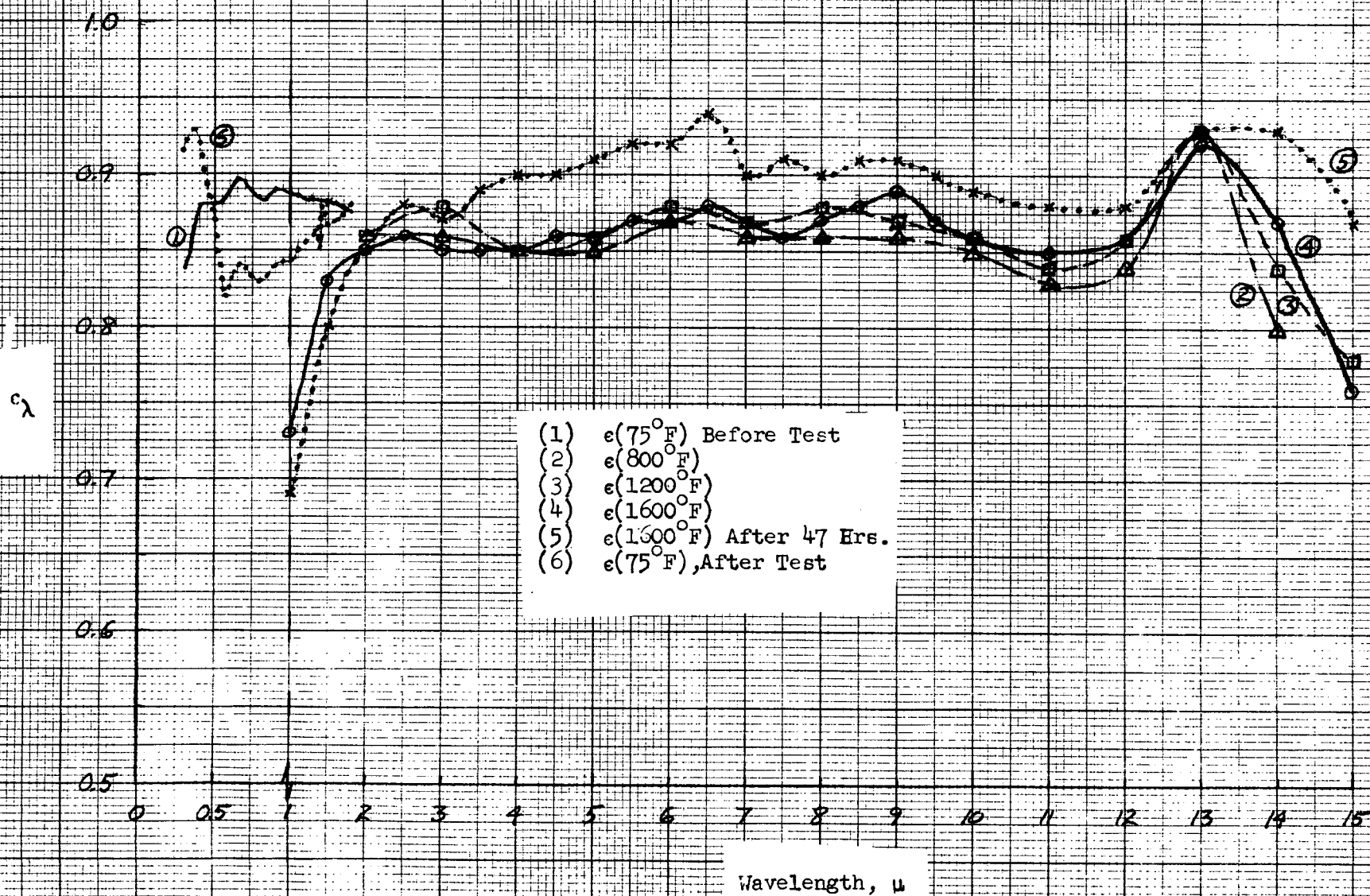
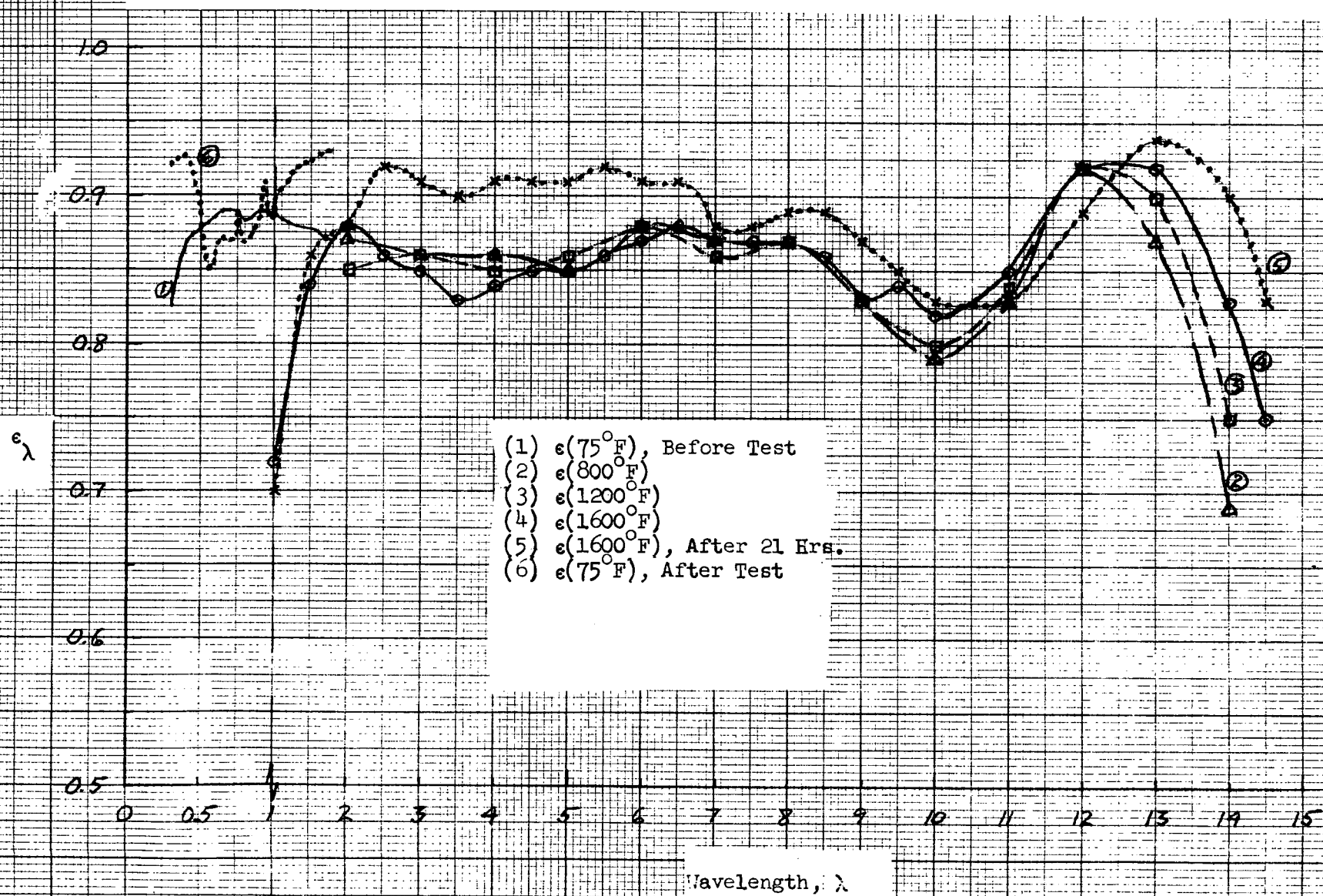
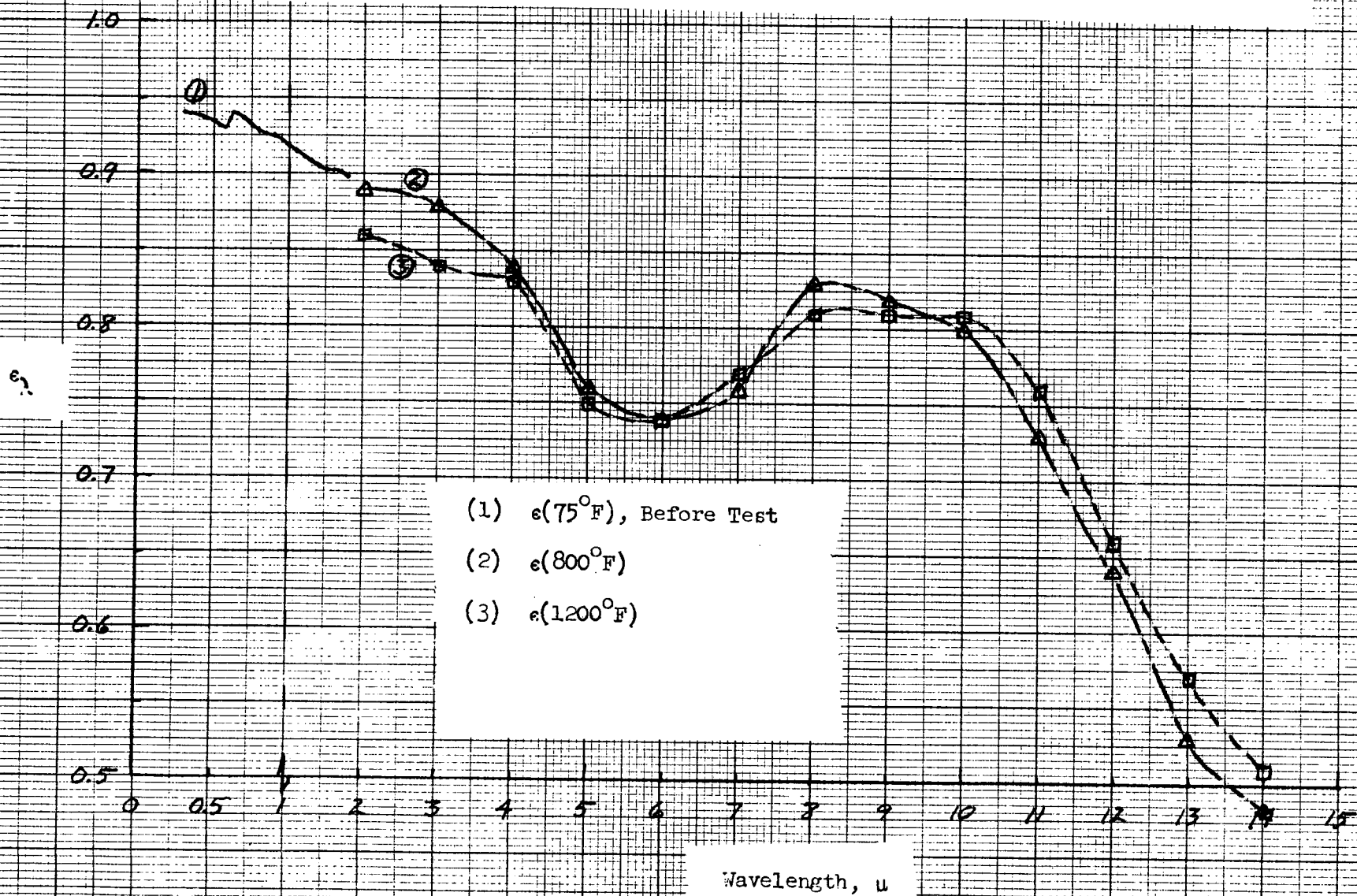


Figure 8. Spectral Emittance of MSFC Oxidized Rene' 41 Sample No. D2.

Wavelength, λ

N-JE-72-2

Figure 9. Spectral Emittance of MSFC Oxidized René 41 Sample No. A2.



Section 6
FUTURE ACTIVITY

Activity for the next monthly reporting period will be directed towards completion of the cold flow checkout tests and radiometer response calibration, and initiation of the materials emittance test program. Recommendations for a plasma gas-heating system will be finalized and forwarded to MSFC for approval.

Appendix A
Additional Distribution Quarterly and Final Reports
Contract NAS8-26304

Lockheed Missiles & Space Company
P.O. Box 504
Sunnyvale, California 94088
Attn: Mr. John Lloyd, Manager, Alternate Space Shuttle Concept Study
Dept. G1-51-Bldg. 538

Space Division
North American Rockwell Corporation
12214 Lakewood Boulevard
Downey, California 90241
Attn: Mr. Joe Monroe

The Boeing Company
P.O. Box 1470
Huntsville, Alabama 35807
Attn: Maxie Brown (Space Shuttle)

Space Division
North American Rockwell Corporation
12214 Lakewood Boulevard
Downey, California 90241
Attn: Mr. B. Hello
Vice President, Corporate Wide General Manager
Space Shuttle Program

McDonnell Douglas Astronautics Company
P.O. Box 516
St. Louis, Missouri 63166
Attn: Mr. Sherman L. Hislop
Director of Booster/Orbiter Integration

CCSD
Michoud Operation
P.O. Box 29200
New Orleans, Louisiana 70129
Attn: Mr. C. E. Tharrott, Dept. 2760

Grumman Aerospace Corporation
Plant 25 - Space Shuttle
Bethpage, L.I., New York 11714
Attn: Mr. Fred Raymer

NASA Langley Research Center
Langley Station
Hampton, Virginia 23365
Attn: Mr. Bland Stein

NASA, Ames Research Center
Moffett Field, California 94035
Attn: Mr. H. Goldstein

NASA, Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: Mr. John Merutka

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433
Attn: Mr. N. Geyer

Arthur D. Little, Inc.
20 Acorn Park
Cambridge, Massachusetts 02140
Attn: Mrs. Jean-Berkowitz-Mattuck

The Boeing Company
P.O. Box 3707
Seattle, Washington 98124
Attn: Mr. W. A. Clayton

McDonnell-Douglas Corporation
Box 516, Dept. 256C
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Attn: Mr. T. Allen

University of California
Thermal Systems Division
Berkeley, California 94720
Attn: Professor C. L. Tien

Grumman Aerospace Corporation
Thermodynamics, Plant 35
Bethpage, Long Island, New York 11714
Attn: Mr. L. Hemmerdinger

Thermophysical Properties Research Center
Purdue University Research Park
2595 Yeager Road
West Lafayette, Indiana 47906
Attn: Mr. D. P. DeWitt/Dr. R. E. Taylor

APPENDIX B
FINANCIAL STATUS REPORT

Contract Value	\$156,886
Expenditures this Month	4,631
Expenditures to Date	133,217
Estimated Funds to Completion	23,669
Anticipated Over/Under Run	-
Estimated Costs of Changes and Authorized but not finalized	-
Estimated Costs of Changes under consideration, but not authorized	-
